It does not occur by chance: a mediation model of the influence of workers' characteristics, work environment factors, and near misses on agricultural machinery-related accidents

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1 **It does not occur by chance: a mediation model of the influence of workers'**

2 **characteristics, work environment factors, and near misses on agricultural**

3 **machinery-related accidents**

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Abstract

Agriculture is among the most hazardous productive sectors, and farm machinery is a major source of injury. In the present study, a mediated model was used to test the role played by workers' characteristics, work environment factors, and near misses in predicting agricultural machinery-related accidents in a sample of Italian users (n = 290). Hours worked per week (via the mediation of an adverse work environment) showed a positive association and years of work experience (via the mediation of risk perception) showed a negative association with the probability of being involved in a near miss, which in turn showed a positive association with the probability of being involved in a machinery-related accident. Implications for tailored preventive interventions are discussed.

Keywords: agriculture; near miss; occupational accident; risk perception; mediation model

Introduction

With the mining and construction industries, agriculture is one of the three most hazardous productive sectors both in developing and industrialized countries [1], with an incidence rate of fatal accidents that is double the average of all other industries [2]. Based on data collected by the International Labour Organization (ILO) [3], in the EU-15, the incidence of fatal accidents in agriculture in 2005 was 0.8 per 10,000 farm workers. The corresponding incidence rate for the mining and construction industries was 0.5. For the US, the National Safety Council [4] reported that the mean fatality rate for the US agricultural industry from 1992 to 2002 was 2.23 deaths per 10,000 farm workers, whereas it was 0.39 per 10,000 workers for all US industries. Farm machinery is a major source of injury [5], and the highest number of fatalities involves tractors, mainly because of tractor rollover [6]. In the United States, Carlson et al.[7] reported 9.6 tractor-related injuries/1000 persons/year. A similar picture emerges in European Union countries [8] and particularly in Italy, where approximately 2,000 of 31,000 injuries that occurred in the agricultural sector in 2013 involved machinery, and 1,000 were tractor-related injuries [9].

49   The literature about occupational accidents shows that the occurrence of an accident involves

50   multiple variables related to the individuals and their environment [10]. The same holds true

51   regarding accidents in agriculture [11]. Two different classes of elements have been identified as

52   the main predictors of being a victim of a farm accident: workers' characteristics and work

53   environment factors. In addition to these two classes of risk factors, another powerful predictor of

54   accidents is the so-called *near misses*, i.e., unplanned events that do not result in any injury, illness

55   or damage only because of a fortunate break in the chain of events [12].

56   ***Workers' characteristics***

57   The main workers' characteristics are socio-demographic variables and those accounting for

58   workers' relation with work [13]. Being an older farmer, working long hours, working alone, and

59   operating on a large farm were found to foster the probability of being involved in farm injuries and

60   fatal tractor overturns [14]. Furthermore, having a low risk perception has been shown to increase

61   operators' exposure to occupational risks and accidents [15]. However, inconsistent results have

62   been found in the literature with regard to the factors affecting risk perception, in particular relating

63   to work experience and familiarity with tasks, machinery and equipment. In some studies,

64   experience and familiarity were shown to reduce risk perception [16]. According to these studies,

65   this occurs because familiarity may lead to overconfidence in the use of the devices: the lack of

66   accidents in the person's history with the device contributes to the idea that 'I could do this with my

67   eyes shut', thus reducing risk perception and the attention rate and increasing the probability of

68   performing an unsafe behavior that may lead to an accident. For instance, a driver's accurate

69   perception of the lateral tilt angle of a vehicle is an important factor in avoiding situations that may

70   potentially lead to a side overturn. Görücü et al. [17], in their study addressing the perception of the

71   lateral tilt angle of agricultural tractors, reported that older and more experienced participants

72   disclosed higher limits of the lateral angle at which they felt uncomfortable and would not have

73   driven the tractor. The result of this perception is depicted by the fatality statistics, which show that

74 older male operators usually represent a large percentage of tractor overturn victims [18]. Other

75 studies, however, noted the opposite result [19]. According to them, individuals in familiar

76 situations might be more likely to perceive the risks because they are more frequently exposed to

77 the risky situation. This may increase compliance with safety practices and reduce the actual risk of

78 accidents. Consistent with this, the results of an investigation of farmers' attitudes toward

79 agricultural tractor innovations showed that the older the tractor users and the longer they had

80 worked in agriculture, the higher their commitment to safe working conditions [20].

81 *Work environment factors*

82 Work environment factors represent the second group of predictors of accidents. They account for

83 workload and work organization [11]. Farm work exposes operators to a high workload due to a

84 combination of different factors. Indeed, farmers usually work longer hours, and mostly alone, than

85 workers in other occupations, and they must perform complex and varied tasks. They also handle

86 different machinery that they must care for and maintain; furthermore, their work may be frequently

87 interrupted by mechanical malfunctions – which occur especially in the case of old machinery – and

88 visitors [13]. These adverse working conditions put high external pressure on farmers, increasing

89 their fatigue and probability of being involved in an accident and being injured [21].

90 *The near misses*

91 Near misses are at the lowest level of the safety pyramid model [22]. they occur more frequently

92 and are smaller in scale than serious accidents, and each major accident is usually preceded by a

93 number of near misses [23]. Near misses have been investigated in different sectors: road and rail

94 traffic [24], plant engineering [25], building safety [26], home safety [27], and healthcare systems

95 [28]. Less is known in the literature about near misses and their determinants in the agricultural and

96 forestry sector than about other safety issues. Some exceptions are represented by the study by

97 Lilley et al. [29], who showed that accidents among forestry workers in New Zealand were

98 associated with having had near-miss injury events, and the literature review on accident prevention

4

99   by Lundqvist et al. [30], which included studies investigating near misses as a useful source of

100 information about farm accidents. However, both the abovementioned studies considered near

101 misses for their effects (accidents) rather than their determinants. Wright and Schaaf [24] showed

102 that near misses and accidents substantially share the same determinants, confirming the idea that

103 near misses may be considered a proxy of being exposed to the risk of suffering a more serious

104 accident.

105 *Motivations and aims of the present study*

106 Many statistics are available worldwide about accidents in the agricultural sector, their incidence,

107 and the characteristics of the injured workers [1]. Less is known, however, about the processes and

108 the relationships between the critical variables leading to an accident. The two different classes of

109 risk elements identified in the literature (workers' characteristics and work environment factors) and

110 their role in predicting the probability of being involved in an accident have systematically been

111 investigated by analyzing survey data with multiple regression models [11,13]. Such models are

112 undoubtedly fruitful. However, they force the researcher to consider all the predictors considered in

113 the study at the same hierarchical level without taking into account that some variables may

114 simultaneously be predictors of some and outcomes of other variables.

115   Regarding this aspect, the review of the literature showed that many variables are involved

116 at different levels in the onset of a farm accident. Experience has an influence on risk perception

117 (though previous results are not consistent regarding the direction of such influence: see

118 McLaughlin et al. [16]; Rogers et al. [19]), and risk perception in turn affects the probability of

119 being involved in occupational accidents [15]. In addition, working for longer hours, alone, and on

120 a large farm has been shown to increase workers' exposure to adverse work environment factors

121 [14]. These are conditions that can trigger near misses [31] and accidents [18]. Therefore, we

122 assumed that the processes leading to farm accidents may be more suitably investigated by adopting

123 a mediation model instead of a multiple regression model. In addition, we assumed that the model

124 tested should include the near misses, which have been reported as important predictors of accidents

125 [12] but nonetheless have been under-investigated in previous studies of accidents in agriculture.

126   Based on these considerations, the present study aimed to investigate the risk factors for

127 agricultural machinery-related accidents in a sample of Italian users, examining the role played by

128 a) workers' characteristics, b) work environment factors, and c) near misses and adopting a

129 mediated model to test the seven different hypotheses (Hs) described hereafter.

130   Based on Myers and Hendricks [13] and on Hwang et al. [14], we expected working alone

131 (H1), farm size (H2) and working hours (H3) to show a positive association with the exposure to

132 adverse work environment factors. Concerning the relation between years of work experience and

133 risk perception, because of the inconsistent results available in the literature, we made two

134 alternative competing hypotheses. If—as in McLaughlin et al. [16]—work experience leads mainly

135 to overconfidence in the use of devices, it should show a negative association with risk perception

136 (H4a); in contrast, if work experience—as in Rogers et al. [19]—leads mainly to an increased

137 situational awareness, it should show a positive association with risk perception (H4b).

138   Furthermore, based on Kogler et al. [31] and on Elkind [15], we postulated that exposure to

139 adverse work environment factors would show a positive association (H5) and risk perception

140 would show a negative association (H6) with near misses. Finally, based on Phimister et al. [23],

141 we expected near misses to show a positive association with being involved in an accident (H7). We

142 analyzed such relations via a mediated model rather than a standard regression to account for the

143 complexity of the associations we hypothesized, with accidents being the outcome of the model;

144 working alone, farm size, hours worked, and years of experience being the predictors (i.e., the

145 exogenous variables); and adverse work environment, risk perception, and near misses being

146 mediators (i.e., outcomes of working alone, farm size, hours worked, and years of experience and at

147 the same time predictors of accidents).

148 **Method**

149   *Participants and setting*

150   The study involved a sample of 290 users of agricultural machinery (272 men, M_{age} = 45.46 years,

151   *SD* = 17.40). The participants worked an average of 39.67 hours per week (*SD* = 23.72) and had

152   been working in agriculture for 26.45 years (*SD* = 18.00).[1] Participants' distributions of gender,

153   age, education, and occupation were in line with those of the Piedmont and Italian agricultural

154   population, as reported in the VI Agricultural Census of 2010 [32,33]. They were recruited from the

155   visitors to the 35th National Exhibition of Agricultural Mechanization in Savigliano, the largest

156   agricultural machinery exhibition in the Piedmont region (northwestern Italy). The 2016 edition of

157   the show (18-20 March) was attended by over 65,000 visitors. The Piedmont region, one of the

158   twenty Italian regions, covers 35% of the Po River catchment, with agriculture taking place on the

159   plain (41% of the utilized agricultural area – UAA), mainly maize-based systems, and on the hills

160   (31% of the UAA), mainly vineyards and winter cereals [34]. The Piedmont region is a good

161   representation of the Italian farming system and rural population since it includes approximately

162   10% of the total Italian UAA. Moreover, over 61,000 of the 1,620,884 Italian agricultural holdings

163   operate in this region [32].

164   Since the agricultural population is spread across the country and has varying operating

165   schedules, agricultural machinery exhibitions are one of the few occasions at which a large and

166   wide-ranging group of agricultural workers comes together. Such events therefore provide a

167   suitable location for appropriate surveys and other data-collection activities [17,35].

168   *Instrument*

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[1] As shown in Table 1 (see below), in our dataset, participants' age and years of experience in agriculture
showed a very strong correlation. To avoid an excessive conceptual overlap and problems of empirical
collinearity, both in the theoretical and in the empirical sections of the paper, we reasoned in terms of years
of experience rather than in terms of age.

169   A 27-item self-administered paper-and-pencil questionnaire was used to gather information about

170   participants' work environment, risk perception, near misses, and accidents. The different sections

171   and items of the questionnaire were designed based on previous instruments [11,29] and on the

172   evidence from a preliminary qualitative study [36]. Risky machinery-related tasks and types of

173   accidents and near misses were selected after an analysis of the statistics regarding the most

174   frequent and serious machinery-related accidents and injuries in Italian agriculture [9]. The

175   questionnaire was pilot-tested with a group of 8 operators before being submitted to the sample of

176   the present investigation.

177   The questionnaire was composed of 3 sections. In the first section, participants were

178   administered a list of 4 adverse work environment factors: sufficient manpower (con-trait),

179   interruptions by machinery malfunctions, interruptions by on-farm visits, and work delay due to the

180   adoption of safety measures. Participants were asked to rate on a 4-point scale (1 = never, 4 =

181   always) how often these 4 situations occurred on their farm. The 3 items related to manpower and

182   interruptions came from Glasscock et al. [11], whereas the adoption of safety measures was

183   indicated by farmers as often causing work delays and thus increasing time pressure in agricultural

184   tasks in a preliminary qualitative study [36]. A confirmatory factor analysis (CFA), performed after

185   reversing the first item, showed that the scale was unidimensional, $CFI = 1.00$, $IFI = 1.00$, $RMSEA$

186    $= .00$ (90% $CI = .00, .08$).[2]

187   In the second section, participants had to report on a 4-point scale (ranging from 1 = not

188   risky at all to 4 = very risky) how risky they considered the following tasks in machinery

189   operations: moving equipment near power lines, manually feeding a wood chipper, using a wood-

190   splitting machine/circular saw, using the tractor on a field without a seatbelt, handling round bales

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[2] We tested the unidimensionality of this and the next scale using CFA instead of Cronbach α because the
    strength of the latter depends, beyond their mean correlation, on the number of items, and our first battery
    was composed of only 4 items.

191 with a front-end loader, working with machinery near ponds or ditches, cleaning a manure spreader

192 while it is in motion, and descending from the tractor without turning the engine off. Items about

193 power lines and working near ponds were taken from Whitman and Field [37], whereas the other

194 items were operations or tasks that are more likely to lead to an accident according to Italian

195 national safety statistics [9]. A CFA showed that the scale was unidimensional, *CFI* = .93, *IFI* = .93,

196 *RMSEA* = .05 (90% *CI* = .00, .09). Participants' scores on these scales were computed as

197 standardized factorial scores.

198   In the third section, participants had to indicate how often in the 12 months preceding the

199 survey they had been involved in 5 different types of events involving agricultural machinery, using

200 a 3-category format (0 = never; 1 = once; 2 = twice or more): fall/thrown from a vehicle; run

201 over/crushed by a vehicle; struck by flying objects, broken parts, or hydraulic fluid; side/rear

202 rollover; and road accident with tractor/equipment. Participants were asked to answer the battery

203 twice, reporting for each event how often they had been involved with (i.e., accident) and without

204 (i.e., near miss) suffering an injury. The list of events was created based on the most common types

205 of accidents involving agricultural machinery according to the statistics from the Italian Workers'

206 Compensation Authority [9]. After dichotomizing participants' answers (contrasting the 0 and the

207 other responses), we computed two scores as sums of their responses to the first and to the second

208 version of the batteries that were used as operationalization of the number of accidents and of near

209 misses occurring in the 12 months preceding the survey. A standard socio-demographic form

210 assessing participants' relation with work (hours worked per week, years of experience in the

211 agricultural sector, farm size and whether they were a sole farmer) ended the questionnaire.

212 ***Procedure***

213 Trained research assistants handed out the questionnaire to people walking through the exhibition.

214 They approached visitors and asked whether farming was their primary or secondary occupation

215 (i.e., being a part-time farmer) and whether they used agricultural machinery at least once a week.

216   In the case of a positive answer, the assistants explained the aims of the study and informed the

217   participants that the questionnaire was anonymous. The questionnaire was in Italian, and its

218   completion took approximately 6-7 min. No incentive was offered to induce visitors to participate

219   in the survey. The response rate was approximately 85%.

220   **Results**

221   Table 1 reports the descriptive statistics for the variables that the study investigated and the

222   correlations among them. Of the participants, 45.9% had been involved in at least an accident and

223   44.8% had been involved in at least a near miss in the 12 months preceding the survey.

224   ---Table 1 about here---

225   A first path analysis model showed that H1 and H2 were falsified. Indeed, being a sole

226   farmer ($b = .04$, $SE = .12$, $p = .74$) and the size of the farm where the participant worked ($b = .00$,

227    $SE = .00$, $p = .13$) showed no significant association with adverse work environment. Thus, we re-

228   ran the model after deleting those variables. All the paths of the resulting model were statistically

229   significant (see Figure 1: betas and standard errors are displayed). The hours worked showed a

230   positive association with working in an adverse environment ($R^2 = .06$), confirming H3. Consistent

231   with H4b and contrary to H4a, years of experience showed a positive association with risk

232   perception ($R^2 = .08$). Consistent with H5 and H6, working in an adverse environment and risk

233   perception, respectively, showed a positive and a negative association with near misses ($R^2 = .07$),

234   which in turn, consistent with H7, showed a positive association with accidents ($R^2 = .08$). Table 2

235   shows that all the indirect effects we tested, even the small ones, were significant. The fit of the

236   model was satisfactory, $\chi^2(9) = 16.44$, $p < .06$, IFI $= .92$, $CFI = .92$, $RMSEA = .05$ ($CI = .00, .09$).[3]

237   ---Figure 1 about here---

238   ---Table 2 about here---

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[3] Parallel analyses, performed by substituting participants' years of experience in agriculture for their age, showed analogous results (available upon request).

Discussion

The present study investigated, via a mediation model, the risk factors for machinery-related accidents in the agricultural sector. The model showed that workers' characteristics are associated with exposure to adverse work environment factors and risk perception, which in turn are associated with the probability of being involved in near misses and accidents. Consistent with the literature about occupational accidents [10], in the present study, different variables were shown to be interwoven in the occurrence of an agricultural machinery-related accident.

Our mediation model noted the more critical variables and at what level they affect the chain of events leading to accidents, suggesting that machinery-related safety issues be addressed by an ergonomic approach (www.iea.cc) This approach considers the individuals in their interaction with the proper tools and tasks of their work environment and allows interventions to be developed in different dimensions (materials vs. practices) and at different levels (individual level vs. farm level) [38] to find the best fit between the worker and the job in terms of health, safety, comfort, and performance [21].

The results of the study showed that regarding workers' factors, working long hours increased the exposure to accidents through the mediation of adverse working situations, such as interruptions and time pressure. A positive association between hours worked and involvement in accidents has already been noted by previous studies both in the agriculture/forestry sector [29] and in other industries [39]. When an operator works long hours, he/she is likely to address many different situations, which increases fatigue and reduces alertness, causing errors and thus enhancing the possibility of being injured in an accident [40]. Interventions addressing this issue may focus on redesigning the work process [41], for instance, by training workers to take systematic rest breaks during their working hours [38] or assisting farmers in managing external pressures [18].

11

263   The worker's experience is another critical workers' factor that, according to the results of

264   the model we tested, enhances risk perception. The outcome of the study contributes to the

265   discussion of the consequences of familiarity with tasks and machinery [16,19], strengthening the

266   assumption of the protective role of this variable. A lack of accidents or near misses in a person's

267   history with a device/machine has been reported to lead to overconfidence in its use and lower risk

268   perception [16]. Similarly, it is reasonable to assume that previous exposure to near misses and

269   accidents is responsible for the positive association between work experience and risk perception

270   found in the present study. In this light, the longer the operator has been working in the field, the

271   more accidents and near misses he/she may have encountered, learning from these events and thus

272   increasing his/her risk awareness and perception [42].

273   The study showed that higher risk perception predicts lower occurrence of near misses and

274   accidents. Risk perception is thus confirmed to play a crucial role in the occurrence of accidents

275   [15], suggesting further investigation, especially in such a hazardous sector as agriculture.

276   Identifying factors that lead to a higher risk perception in agricultural operators will allow the

277   development of training interventions and information campaigns tailored to maximize their

278   preventive effectiveness.

279   In the present study, near misses appeared to be a significant predictor of accidents. This

280   result confirms the importance of investigating near misses to prevent more serious accidents [12],

281   including in the agricultural sector, in which near misses have been largely neglected. Farmers may

282   be trained to recognize and annotate near misses to early identify critical aspects leading to

283   accidents and intervene to eliminate or reduce them. According to Kogler et al. [31], the main

284   preventive measures indicated by farmers to help them avoid near misses are, in order of

285   importance, increased training in agricultural operations, mechanical adaptations, and easy-to-

286   understand and short written operating instructions. Regarding the importance of training, the

287   evidence by Burke et al. [43] raises some considerations about the need to adopt not only such

288   conventional training methods as pamphlets, lectures, and videos but also more engaging behavioral

289   modeling techniques – such as hands-on demonstrations and behavioral simulations – to promote

290   the correct and safe use of machinery and therefore reduce accidents.

291   Clear and short operating instructions, such as use and maintenance manuals, and clear and

292   effective safety information about machinery, such as pictorial representations, are additional

293   important elements to promote the safe use of machinery. Operator manuals are supposed to be an

294   exhaustive source of information for the safe use and maintenance of agricultural machinery, but

295   previous studies have shown that they are often unread [44] due to poor document design, requiring

296   a non-negligible cognitive load to decipher pages packed with information that is mainly intended

297   for the legal protection of the manufacturer. Pictorial representations affixed to machinery are visual

298   tools to convey relevant safety information, but they are not as effective as they are supposed to be

299   [45,46]. A re-design of these sources of safety information must be considered to enhance safety in

300   machinery use.

301   Contrary to the findings of previous studies [13,14] no significant associations between

302   being a sole farmer and farm size on the one hand and exposure to accidents on the other hand

303   emerged. Accidents occur in all types of farms of any dimension and to all kinds of holders: safety

304   interventions and campaigns should therefore address all kinds of farms and farm operators without

305   considering some groups more at risk than others.

306   *Limitations of the present study and possible research developments*

307   Some limitations of the present study should be acknowledged. The survey was carried out in the

308   Piedmont region of northwestern Italy. On the one hand, the Piedmont farming system is a good

309   representation of Italian agriculture, and performing the study at a local level allowed us to test a

310   parsimonious model: participants in the study had a similar cultural background; thus, we could

311   manage comparable data without controlling for a plethora of socio-demographic variables [47].

312   Even though the socio-demographic characteristics of our participants were in line with those of the

313 Italian rural population reported in the last agricultural census, it is apparent that only the people

314 who attended the Exhibition of Agricultural Mechanization in Savigliano could participate in our

315 survey. More generalizable results would be available from a random sample of agricultural

316 workers.

317   Another limitation is that our data on near misses and accidents were based solely on self-

318 reports, and the recall covered quite a long period (12 months). Even though self-reporting is a quite

319 common strategy in this kind of investigation [29,48], and 12 months is the usually considered

320 period [11], it is possible that the participants' responses were affected by memory bias, thus

321 resulting in a gap between self-reported and actual involvement in the reported events [49]. To

322 obtain more accurate information about these variables, a possible direction of study would be to

323 register near misses and accidents weekly (as for the accidents studied in Glasscock et al. [11]).

324   Finally, it should be noted that the bivariate correlations between our variables were not

325 very strong, like the variance of the dependent variables we have explained. Moreover, consistent

326 with Chaplin [50], the indirect effects that we detected were small. The weakness of these effects

327 may likely be attributed, at least in part, to methodological rather than theoretical reasons. Indeed,

328 as we performed field research, we could measure our variables using short scales; thus, we had to

329 manage measures that were plausibly distorted, at least in part, by measurement error. Stronger

330 indirect effects will likely stem from new research performed using longer scales.

331   Possible future developments of the research could further explore the relationship between

332 adverse work environment factors and accidents, considering the safety behaviors [11] and coping

333 strategies adopted when dealing with adverse and stressful conditions [51] as mediators of the

334 relationship. Moreover, it would be interesting to increase our understanding of the factors

335 contributing to farm accidents in two ways: first, via more objective techniques of data collection,

336 such as the observation of farmers interacting with different machines, to identify risky behaviors

337 that can increase the probability of being involved in an accident (as in Mann et al., [52]), and

338 second, taking directly into account the issue of the age of agricultural machinery, which is known

339 to play a role in the onset of agricultural accidents [53]. The use of aging machines with inadequate

340 safety engineering represents a constant source of risk, as operations involving high numbers of

341 disturbances, e.g., machinery breakdowns, have a higher accident probability [54]; our

342 questionnaire item about frequent interruptions of farm work due to machinery malfunctions was

343 based on this evidence. However, the age of machinery could be explicitly assessed as a factor that

344 could affect the mediators or the outcomes of our model.

345 Furthermore, the reasons underlying the positive association found in the present study

346 between work experience and risk perception could be further investigated. For instance, a farmer's

347 previous history of near misses and accidents could be evaluated and added as a mediator in the

348 relationship between experience and risk perception, or expert and novice farmers could be

349 observed/interviewed when interacting with machinery to identify the ways in which they perform

350 their complex and varied tasks and the different strategies adopted to reduce risks (as in Mann et al.

351 [52]).

352 Furthermore, in future research, data collection on farm accidents and near misses could be

353 extended over a longer period. This would allow researchers to investigate the possible mediation

354 effects of previous exposure to such events on the relationship between work experience and risk

355 perception [42]. Finally, a mediation model such as the one used in the present study could be

356 adopted to investigate accidents related to livestock [55] and pesticides [56], which are other major

357 causes of accidents and health issues in the agricultural sector.

358 **Conclusions**

359 The chain of events leading to an occupational accident deserves particular attention in agriculture,

360 due to the high hazardousness of this sector. The results of the present study showed that different

361 critical variables intervene at different levels in determining an agricultural machinery-related

362 accident. Hours worked and work experience affected the probability of being involved in an

363 accident through the mediation of adverse work environment and risk perception and then of near

364 misses. These results suggest that different facets of the interaction between the operator and his/her

365 work environment should be considered when designing preventive interventions, ranging from a

366 re-design of the actual work processes to the development of strategies to enhance workers' risk

367 perception. Interventions should also focus on near misses, making the reporting and analysis of

368 these events a widespread and systematic practice among farmers and farm workers [12].

369 Furthermore, interventions should support the protective role played by work experience by

370 adopting engaging training methods as behavioral modeling in the use of machinery to optimize the

371 learning of safety practices and safe behaviors. Finally, it must be noted that, as found by Kogler et

372 al. [31] with regard to near misses, any solution and intervention aimed at improving the quality of

373 farmers' work life and reducing accidents must also be disseminated to the farming populations in

374 formats that are acceptable and understandable [21].

375

376 **Disclosure statement**

377 The authors have no competing interests to declare.

381 **References**

382 [1] ILO. Agriculture; plantations; other rural sectors [Internet]. Geneva; International Labour

383   Organization; 2014 [cited 2016 Sept 02]. Available from:

384   http://www.ilo.org/global/industries-and-sectors/agriculture-plantations-other-rural-

385   sectors/lang--en/index.htm

386 [2] ILO. Safety and health in agriculture. Geneva, Switzerland; International Labour Office; 2011.

387   [3] ILO. World day for safety and health at work [Internet]. Geneva; International Labour

388   Organization; 2005 [cited 2016 Sept 02]. Available from:

389   http://www.ilo.org/public/english/protection/safework/index.htm

390   [4] NSC. Injury facts: 2004 ed. Itasca (IL): National Safety Council; 2004.

391   [5] Narasimhan GR, Peng Y, Crowe TG, et al. Operational safety practices as determinants of

392   machinery-related injury on Saskatchewan farms. Accident Anal Prev. 2010;42:1226-1231.

393   [6] Swanton AR, Young TL, Leinenkugel K, et al. Nonfatal tractor-related injuries presenting to a

394   state trauma system. J Safety Res. 2015;53:97-102.

395   [7] Carlson KF, Gerberich SG, Church TR, et al. Tractor-related injuries: a population-based study

396   of a five-state region in the Midwest. Am J Ind Med. 2005;47:254-264.

397   [8] European Commission. Causes and circumstances of accidents at work in the EU. Luxembourg:

398   Office for Official Publications of the European Communities; 2009.

399   [9] INAIL. Relazione audizione Commissione Agricoltura e Produzione Agroalimentare [Report

400   from the Commission on Agriculture and Food Production]. Rome: Istituto Nazionale

401   Assicurazione Infortuni sul Lavoro; 2015.

402   [10] Reason J. Human error: models and management. Brit Med J. 2000;320;768-770.

403   [11] Glasscock DJ, Rasmussen K, Carstensen O, et al. Psychosocial factors and safety behaviour as

404   predictors of accidental work injuries in farming. Work Stress 2006;20:173-189.

405   [12] NSC. Near miss reporting systems. Itasca (IL): National Safety Council; 2013.

406   [13] Myers JR, Hendricks KJ. Agricultural tractor overturn deaths: assessment of trends and risk

407   factors. Am J Ind Med. 2010;53:662-672.

408   [14] Hwang S, Gomez MI, Stark AD, et al. Severe farm injuries among New York farmers. Am J

409   Ind Med. 2001;40:32–41.

410   [15] Elkind PD. Perceptions of risk, stressors, and locus of control influence intentions to practice

411   safety behaviors in agriculture. J Agromedicine 2008;12:7-25.

412 [16] McLaughlin AC, Fletcher LM, Sprufera JF. The aging farmer: human factors research needs in

413   agricultural work. Proc Hum Fact Ergon Soc Annu Meet. 2009;53:1230-1234.

414 [17] Görücü S, Cavallo E, Murphy JD. Perceptions of tilt angles of an agricultural tractor. J

415   Agromedicine 2014;19:5-14.

416 [18] Lizer SK, Petrea RE. Health and safety needs of older farmers part II. Agricultural injuries.

417   Workplace Health Saf. 2008;56:9-14.

418 [19] Rogers WA, Lamson N, Rousseau GK. Warning research: an integrative perspective. Hum

419   Factors 2000;42:102-139.

420 [20] Cavallo E, Ferrari E, Bollani L, et al. Strategic management implications for the adoption of

421   technological innovations in agricultural tractor: the role of scale factors and environmental

422   attitude. Technol Anal Strateg. 2014;26:765-779.

423 [21] McLaughlin AC, Mayhorn CB. Avoiding harm on the farm: human factors. Gerontechnology

424   2011;10:26-37.

425 [22] Reason JT. Managing the risks of organizational accidents. Aldershot (UK): Ashgate; 1997.

426 [23] Phimister JR, Oktem U, Kleindorfer PR, et al. Near-miss system analysis: phase I.

427   Philadelphia, (PA): Wharton School, Center for Risk Management and Decision Processes;

428   2000.

429 [24] Wright L, Schaaf T. Accident versus near miss causation: a critical review of the literature, an

430   empirical test in the UK railway domain, and their implications for other sectors. J Hazard

431   Mater. 2004;111:105–110.

432 [25] Uth HJ, Wiese N. Central collecting and evaluating of major accidents and near-miss-events in

433   the Federal Republic of Germany - results, experiences, perspectives. J Hazard Mater.

434   2004;111:139-145.

435 [26] Wu W, Gibb AG, Li Q. Accident precursors and near misses on construction sites: an

436   investigative tool to derive information from accident databases. Safety Sci. 2010;48:845-858.

437 [27] Marsh P, Kendrick D. Near miss and minor injury information - can it be used to plan and

438   evaluate injury prevention programmes? Accident Anal Prev. 2000;32:345-354.

439 [28] Lyons PG, Arora VM, Farnan JM. Adverse events and near-misses relating to intensive care

440   unit–ward transfer: a qualitative analysis of resident perceptions. Ann Am Thorac Soc.

441   2016;13:570-572.

442 [29] Lilley R, Feyer AM, Kirk P, et al. A survey of forest workers in New Zealand: do hours of

443   work, rest, and recovery play a role in accidents and injury? J Safety Res. 2002;33:53-71.

444 [30] Lundqvist P, Gustafsson B. Accidents and accident prevention in agriculture a review of

445   selected studies. Int J Ind Ergonom. 1992;10:311-319.

446 [31] Kogler R, Quendler E, Boxberger J. Near accidents with agricultural vehicles, machinery and

447   equipment in Austria in the year 2013. Agricultural Engineering International: CIGR Journal

448   2015;17:141-157.

449 [32] INEA. Italian agriculture in figures 2013. Rome: Istituto Nazionale di Economia Agraria;

450   2014.

451 [33] ISTAT. 6° Censimento generale dell'agricoltura 2010. Caratteristiche strutturali delle aziende

452   agricole [6th Agricultural Census 2010. Characteristics of farms]. Rome: Istituto Nazionale di

453   Statistica; 2010.

454 [34] Bassanino, M, Sacco D, Zavattaro L, et al. Nutrient balance as a sustainability indicator of

455   different agro-environments in Italy. Ecol Indic. 2011;11:715-723.

456 [35] Cavallo E, Ferrari E, Bollani L, et al. Attitudes and behaviour of adopters of technological

457   innovations in agricultural tractors: a case study in Italian agricultural system. Agr Syst.

458   2014;130:44–54.

459 [36] Caffaro F, Lundqvist P, Micheletti Cremasco M, et al. Machinery-related perceived risks and

460   safety attitudes in senior Swedish farmers. J Agromedicine. Forthcoming 2017.

461 [37] Whitman SD, Field WE. Assessing senior farmers' perceptions of tractor and machinery-

462   related hazards. J Agric Saf Health. 1995;1:199-214.

463 [38] Kirkhorn SR, Earle-Richardson G, Banks RJ. Ergonomic risks and musculoskeletal disorders

464   in production agriculture: recommendations for effective research to practice. J

465   Agromedicine, 2010;15:281-299.

466 [39] Wagstaff AS, Lie JAS. Shift and night work and long working hours-a systematic review of

467   safety implications. Scand J Work Environ Health. 2011;37:173-185.

468 [40] Greubel J, Nachreiner F. The validity of the risk index for comparing the accident risk

469   associated with different work schedules. Accident Anal Prev 2013;50:1090-1095.

470 [41] Baron S, Estill C, Steege A, et al. Simple solutions: ergonomics for farm workers. Cincinnati,

471   (OH): National Institute for Occupational Safety and Health; 2001.

472 [42] Lindberg AK, Hansson SO, Rollenhagen C. Learning from accidents–what more do we need to

473   know? Safety Sci. 2010;48:714-721.

474 [43] Burke MJ, Sarpy SA, Smith-Crowe K, et al. Relative effectiveness of worker safety and health

475   training methods. Am J Public Health. 2006;96:315-324.

476 [44] Tebeaux E. Improving tractor safety warnings: readability is missing. J Agric Saf Health

477   2010;16:181–205.

478 [45] Caffaro F, Cavallo E. Comprehension of safety pictograms affixed to agricultural machinery: a

479   survey of users. J Safety Res. 2015;55:151–158.

480 [46] Caffaro F, Mirisola A, Cavallo E. Safety signs on agricultural machinery: pictorials do not

481   always successfully convey their messages to target users. Appl Ergon. 2017;58:156-166.

482 [47] Smith-Jackson T, Wogalter MS, Quintela Y. Safety climate and pesticide risk communication

483   disparities in crop production by ethnicity. Hum Factor Ergon Man. 2010;20:511–525.

484 [48] Nilsson, K., Pinzke, S., Lundqvist, P. Occupational injuries to senior farmers in Sweden. J

485   Agric Saf Health 2010;16(1):19-29.

486   [49] Burton S, Blair E. Task conditions, response formulation processes, and response accuracy for

487   behavioral frequency questions in surveys. Public Opin Quart. 1991;55:50-79.

488   [50] Chaplin WF. The next generation of moderator research in personality psychology. J Personal

489   1991;59:143-178.

490   [51] Stave C, Pousette A, Törner M. A model of the relations between risk perception and self-

491   reported safety activity. J Occup Ergon. 2006;6:35-45.

492   [52] Mann DD, Hesketh A, Morrison JB. Comparison of forward-facing and backward-facing

493   tractor egress. Canadian Biosystems Engineering 2016;58:2.1-2.8.

494   [53] Pyykkönen M. Aherin B. Occupational Health and Safety in Agriculture. In: Jakobsson C,

495   editor. Ecosystem Health and Sustainable Agriculture 1. Sustainable agriculture. Uppsala: The

496   Baltic University Programme, Uppsala University; 2012. p. 391-401.

497   [54] Suutarinen, J. Occupational accidents in Finnish agriculture: Causality and managerial aspects

498   for prevention [doctoral dissertation]. Agrifood Research Reports 39. Helsinki: MTT

499   Agrifood Research Finland [cited 2017 29 Jul]. Available from:

500   http://jukuri.luke.fi/bitstream/handle/10024/440983/met39.pdf?sequence=1

501   [55] Lindahl C, Lundqvist P, Hagevoort GR, et al. Occupational health and safety aspects of animal

502   handling in dairy production. J Agromedicine. 2013;18:274-283.

503   [56] Emery SB, Hart A, Butler-Ellis C, et al. A review of the use of pictograms for communicating

504   pesticide hazards and safety instructions: implications for EU policy. Hum Ecol Risk Assess.

505   2015;21:1062-1080.

Table 1. Descriptive statistics for the variables we used and correlation among them

	Mean	SD	1	2	3	4	5	6	7	8	9
1. Worked hours per week	39.67	23.76	-	-.15*	-.12*	.28***	-.19***	.24***	-.13*	-.07	-.03
2. Age	45.47	17.40		-	.82***	-.14*	.29***	-.18**	.23***	-.10	-.08
3. Years of experience in agriculture	26.45	18.00			-	-.10	.22***	-.11	.23***	-.12*	-.10
4. Farm size (ha)	33.83	53.40				-	-.18**	.15*	-.10	-.05	-.06
5. Sole farmer (0 = no, 1 = yes)	.37	.48					-	-.04	.12*	-.03	.01
6. Adverse work environment	0.00	1.00						-	.01	.13*	.15**
7. Risk perception	0.00	1.00							-	-.13*	.09
8. Near misses	1.11	1.71								-	.97***
9. Accidents	0.99	1.52									-

Note. The "mean" of being a sole farmer is the proportion, on a 0-1 scale, of the participants who reported to be a sole farmer. When being a sole farmer is involved, the point-biserial correlation coefficient is displayed. *** $p < .001$. ** $p < .01$. * $p < .05$.

1   Table 2. Indirect effects of the exogenous variables and of the mediators.

	Years of experience in agriculture	Worked hours per week	Risk perception	Adverse work environment
Risk perception				
Adverse work environment				
Near misses	-.00*	.01**		
Accidents	.00**	.00**	-.23**	.00**

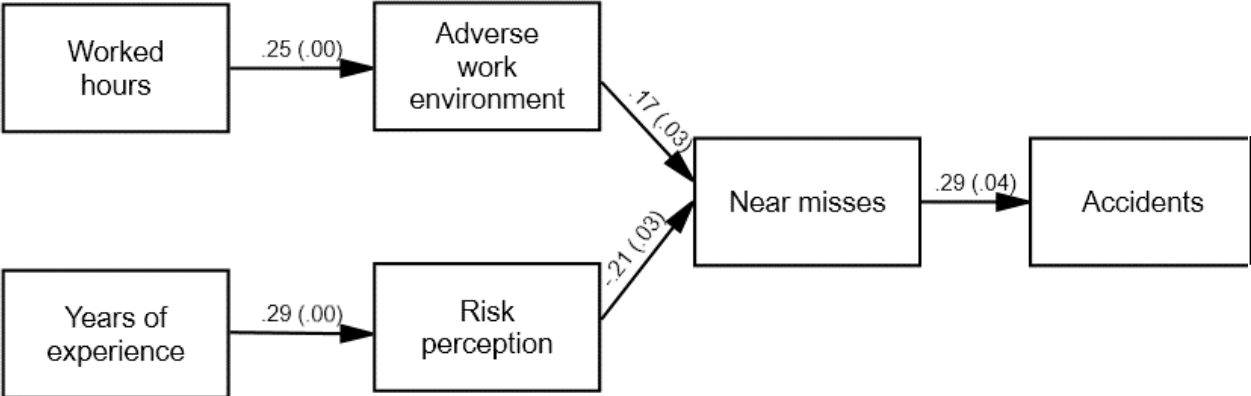2   *Note*. ** $p < .01$. * $p < .05$.

3   Figure caption

4   Figure 1. Workers' characteristics predict accidents through the mediation of adverse work

5   environment, risk perception, and near misses.

6

7

8

9   Figure 1

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